

1.2 Blood Vessels

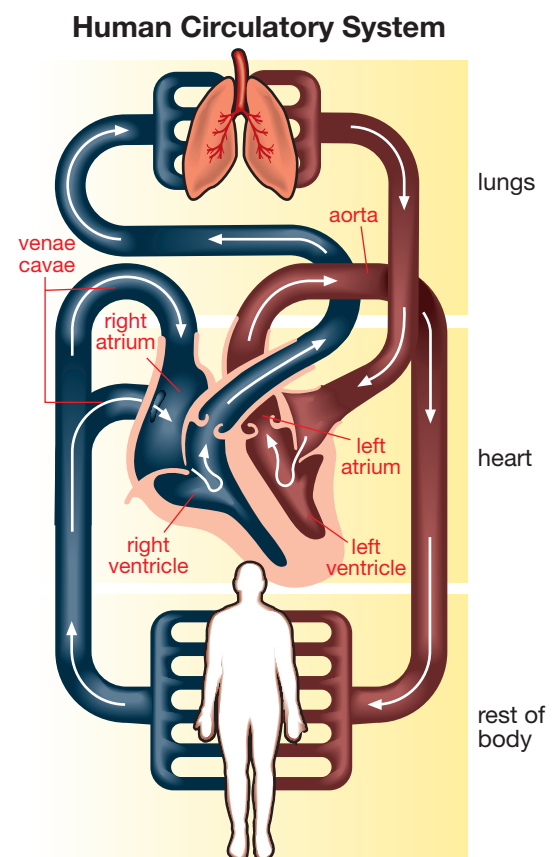


Figure A1.6: Glacial meltwater flows into the Bow River, which supplies about one million people with drinking water in southern Alberta.

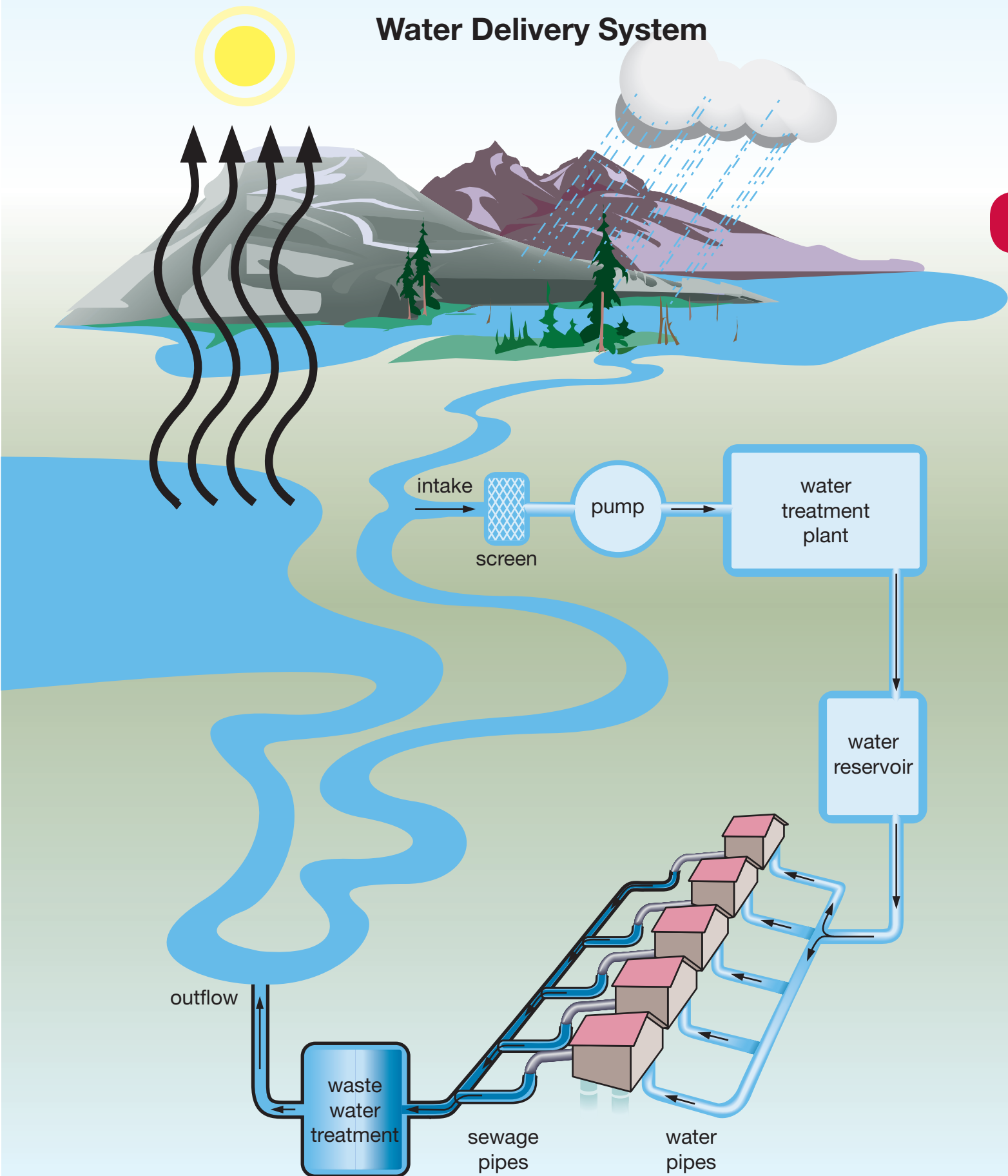
The water that most Albertans drink begins as melt water high in the Rocky Mountains. Rivers then carry this water to communities throughout the province where it is pumped to water purification facilities and reservoirs before moving to people's homes. Each dwelling requires two piping systems: one to bring in the clean water and another to remove the waste water.

Because both systems transport fluids, the circulatory system of the human body can be compared to the water delivery system in a city or town. The cells in people's bodies have similar needs to the residents of a home. Every cell in your body, from the cells that make up the pumping muscles of the heart to the faraway cells in the tips of your toes, must be constantly supplied with blood. The sewage waste water collected at each home must be quickly removed and wastes must not be allowed to mix with the clean water coming from the pumping station, so wastes are transported in separate pipes. The blood that leaves the heart through the aorta is rich in oxygen and nutrients. This blood must be pumped in separate vessels from the blood that is full of carbon dioxide and wastes.

Just as cities and towns must have a fast and efficient way of transporting clean water to residents and of removing waste water, the body's circulatory system must also work to quickly and efficiently transport blood to and from the cells.



Water Delivery System



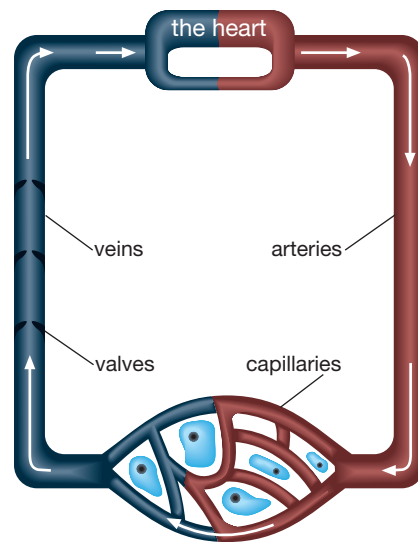
The Pathway of Blood

As you saw in Lesson 1.1, the basic components of the human circulatory system are the heart, which pumps the blood; the blood vessels that transport the blood to all parts of the body; and the blood.

Three types of blood vessels transport the blood. A blood vessel that carries blood away from the heart is called an **artery**, while a blood vessel that transports blood toward the heart is called a **vein**. Both arteries and veins branch into smaller vessels to effectively reach every part of the body. A **capillary** is a microscopic tube that connects the smallest branch of an artery to the tiniest branch of a vein. Capillaries are thin-walled porous vessels that allow materials, such as gases and fluids, to be exchanged with the body's cells. Every living cell in the body must be close to a capillary to remain alive and functioning.

To keep the facts straight about arteries and veins, many students use this memory device:

Arteries carry blood Away from the heart.



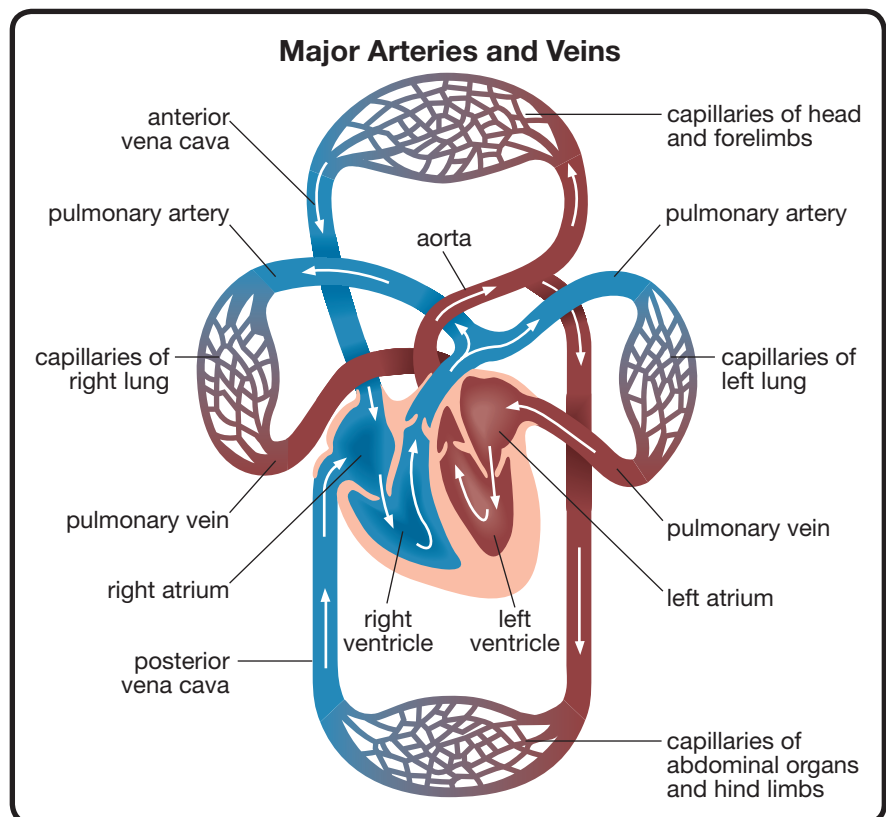
Major Arteries and Veins

The deoxygenated blood arrives back to the heart from the body's major veins, which flow into the **venae cavae**, the largest veins in the body. The blood from each vena cava is carried to the heart's right side where it is pumped to the lungs through the **pulmonary arteries**. Within the capillaries of the lungs, the blood exchanges carbon dioxide for oxygen. The oxygen-rich blood then returns to the heart's left side through the **pulmonary veins**. The word *pulmonary* means "having to do with the lungs" because it comes from *pulmo*, the Latin word for lungs. This is why the movement of blood into and out of the lungs is called pulmonary circulation.

Except for the pulmonary vein, blood that flows through the veins is low in oxygen. Whereas oxygen-rich blood is red in colour, oxygen-poor blood is a darker shade of red. In diagrams, the difference in blood colour is emphasized by using completely different colours—red for oxygen-rich blood and blue for oxygen-poor blood.

Oxygen-rich blood leaves the heart by travelling through the largest artery in the body, known as the **aorta**. Recall that the first branches of the aorta are the coronary arteries, which supply oxygen and nutrients to the heart muscle itself. These arteries appear on the surface of the right and left ventricles. The aorta divides further into other arteries that carry blood to the major organs and body tissues.

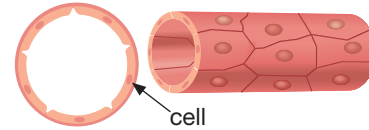
- ▶ **artery:** a thick-walled blood vessel that carries blood away from the heart
- ▶ **vein:** a thin-walled blood vessel with valves that carries blood toward the heart
- ▶ **capillary:** a tiny blood vessel that connects the smallest branch of an artery to the smallest branch of a vein
- ▶ **vena cavae:** the largest veins in the body that carry oxygen-poor blood to the heart
- ▶ **pulmonary artery:** the large blood vessel that carries oxygen-poor blood from the heart's right ventricle to the lungs
- ▶ **pulmonary vein:** the large blood vessel that carries oxygenated blood from the lungs to the heart's left atrium
- ▶ **aorta:** the largest artery in the body; carries oxygen-rich blood from the left ventricle of the heart



Practice

11. The body's circulatory system can be compared to a community's water system.
 - a. Identify the parts of the body's circulatory system that correspond to the community's water pipes, sewage pipes, pump, and water.
 - b. Describe at least two limitations of the comparison between a community's water system and the body's circulatory system.
12. Identify the major artery or vein that best matches each description.
 - a. carries oxygen-poor blood from the heart to the lungs
 - b. the body's largest artery
 - c. carries oxygen-rich blood from the aorta to nourish heart tissues
 - d. carries oxygen-rich blood to the heart
 - e. carries oxygen-poor blood to the heart from the body's tissues
13. It is a common misconception that arteries always carry oxygen-rich blood and veins always carry oxygen-poor blood. Explain why this concept is not true in the case of pulmonary circulation.
14. A capillary is a microscopic structure. Its walls are comprised of only one layer of very thin cells.

cross section of a capillary

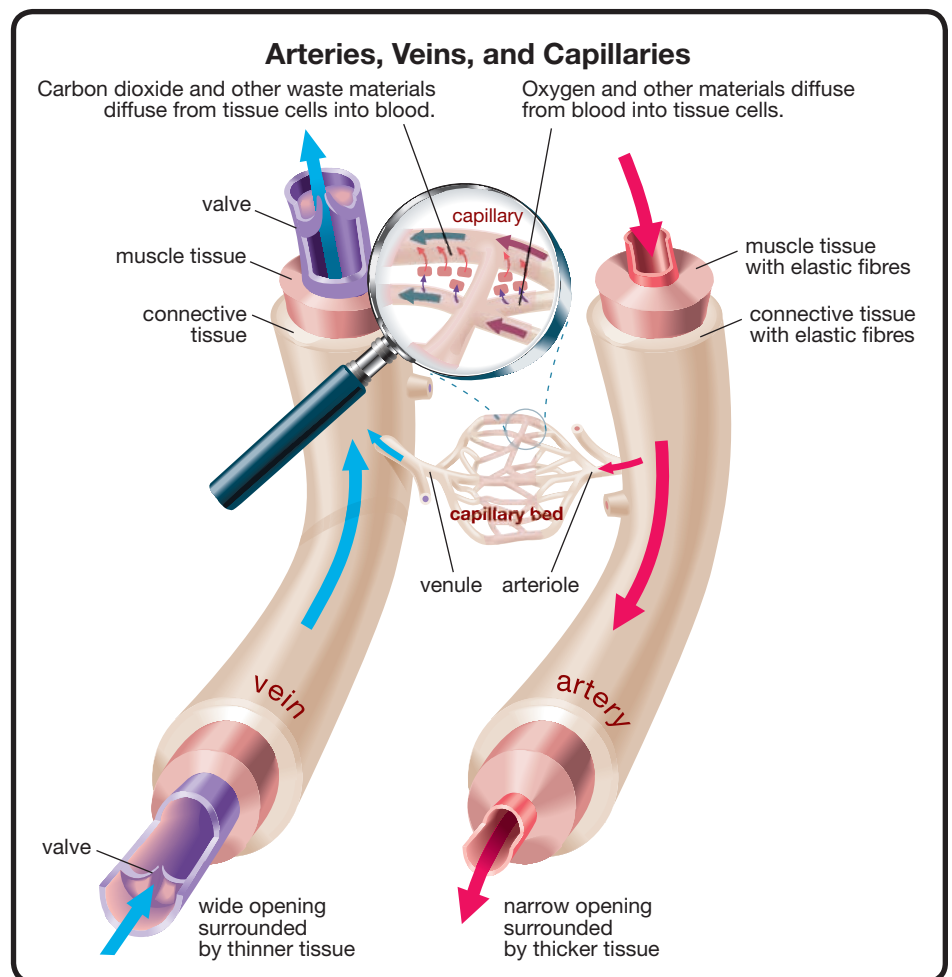


Explain why it is important for the walls of capillaries to be thin.

The Specialization of Blood Vessels

The blood vessels of the circulatory system are specialized for their specific functions. Arteries have thick elastic walls to withstand the pressure of the pumping heart. Except in the case of the pulmonary artery, the blood that flows in the arteries is oxygen-rich. This oxygenated blood is bright red in colour, and arteries other than the pulmonary artery are usually coloured red in circulatory system diagrams. As the arteries get farther away from the heart and aorta, they branch out and get smaller in diameter and lower in pressure. These smaller branched arteries are called **arterioles**.

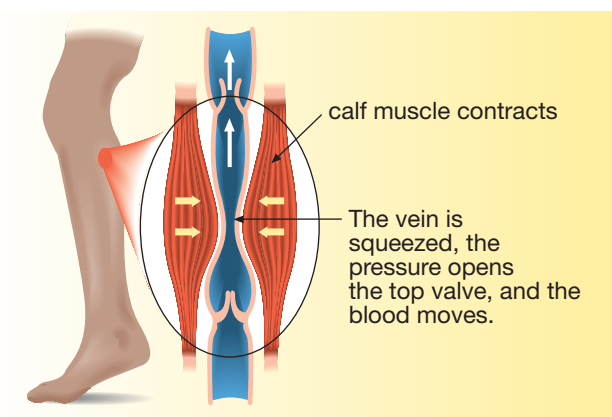
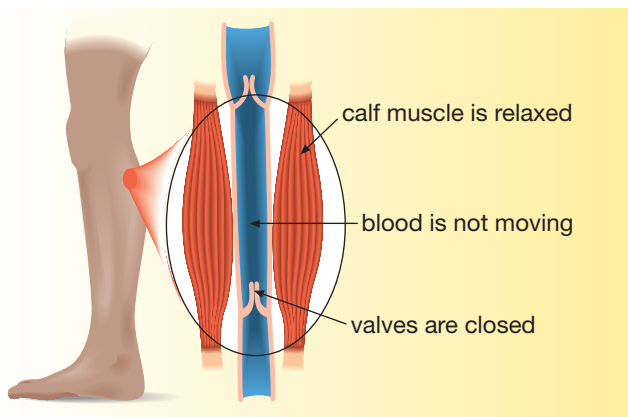
► **arteriole:** a small artery that joins a larger artery to a capillary



Arterioles are attached to the very thin-walled capillaries. The capillary is the place where needed nutrients, like oxygen and glucose, are exchanged for wastes—like carbon dioxide. The capillary walls are only one-cell thick because they need to be thin enough for the exchange of gases to take place by diffusion. Capillaries exist in a **capillary bed**, which is a web of capillaries surrounding the cells of body tissues. There are thousands of kilometres of capillaries in a human body. If you lined up all of the blood vessels end to end, they would wrap around Earth's equator at least four times!

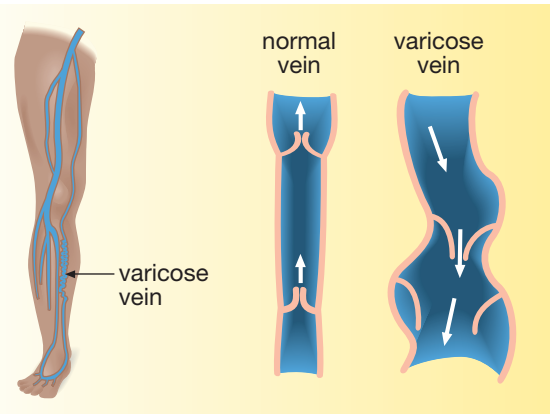
After the blood—depleted of oxygen and nutrients—leaves the capillary, it flows into the branches of veins called **venules**. The blood in venules and the larger veins has a much lower pressure than the blood pressure in an artery, so the walls of veins do not need to be as thick and elastic as the walls of arteries. The low-pressure blood has to get back to the heart against the pull of gravity. This is accomplished with the help of one-way valves in veins that prevent a backflow of blood, and also by the action of contracting body muscles.

- ▶ **capillary bed:** a network of capillaries in a particular area or organ of the body
- ▶ **venule:** a small vein that joins a larger vein to a capillary
- ▶ **varicose vein:** an enlarged, twisted vein near the surface of the skin resulting from poorly functioning valves



Varicose Veins

As a person moves, the moving muscles push on blood in the veins while one-way venous valves prevent a backflow of blood and direct the blood back toward the heart. If the veins become stretched and the valves are damaged, blood in the veins pools and the veins become raised in a condition called **varicose veins**. People who spend much of their day standing have a greater tendency to develop varicose veins.



Practice

15. A blood cell travels through different blood vessels as it passes through the circulatory system after leaving the heart. The blood vessels involved include the following terms: capillary, vein, venule, artery, and arteriole.

Read each of the following descriptions and match each blood vessel term with a description.

- a. Large one-way valves in this vessel help direct blood back to the heart.
 - b. These vessels are so small that blood cells must pass in single file.
 - c. Capillaries converge into this vessel before entering a vein.
 - d. This vessel is the pathway for oxygen-rich blood to enter capillaries.
 - e. This vessel has thick walls with elastic fibres.
16. Consider the numbered list of blood vessels you used in question 15. Beginning with oxygen-rich blood that leaves the heart, place these terms in the order in which they are encountered by a blood cell.
17. Explain why circulatory problems often occur with people who are bedridden or with inactive people who seldom use their muscles.
18. Why do varicose veins most often occur in the lower legs?
19. Why should people who spend much of their workday standing up ensure that they elevate their feet at the end of the day?

Try This Activity

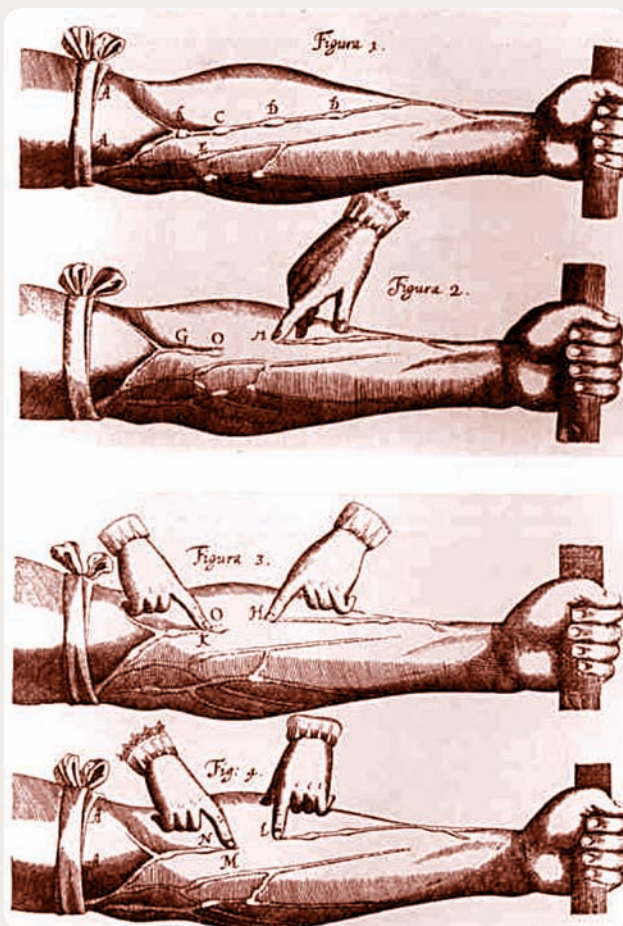
William Harvey's Experiment



Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

British scientist William Harvey helped prove that blood circulates in a closed system of blood vessels rather than swishing back and forth like tides, as was previously believed. Part of his investigation looked at the role of valves of the veins.



Purpose

You will observe the action of the valves working within the veins in the back of your hand.

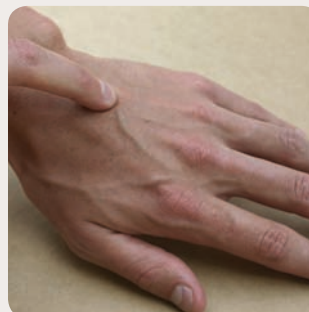
Procedure

step 1: Lay your hand flat on a table so that you can see the veins on the top of your hand. Note that these photographs show the procedure using veins on your left hand.



step 2: Describe the appearance of the veins. Do the veins branch out or are they straight? Do the veins bulge more in certain areas? Record your observations.

step 3: Locate a straight section of a prominent vein. Firmly place the middle finger of your other hand on the end of this straight section of veins closest to your fingers.



step 4: While continuing to push down with your middle finger, take the index finger of your other hand and push down close to the middle finger on the same vein.



step 5: Continue to apply pressure with both fingers, and slide your index finger toward your wrist until you reach the end of the vein's straight section.



step 6: While continuing to apply pressure with your middle finger, release your index finger.



step 7: Carefully observe the straight section of the vein that used to be between the two fingers. Does blood flow back into the vein? Is there observable evidence of a valve's presence?

step 8: Repeat the process described in steps 3 to 7 with the following modifications:

- Place the index finger at the end of the straight section of vein closest to the wrist.



- Then place the middle finger next to the index finger. Slide the middle finger toward the fingers, away from the wrist.
- Release the middle finger and see if the blood flows back into the veins.

Observations

1. Describe your observations from steps 2, 7, and 8.

Analysis

2. State whether it was easier or more difficult to push blood in the veins away from the heart than it was to push blood toward the heart.
3. Use your observations to sketch the veins in your hand. Indicate the location of the valves.

Conclusion

4. Write a concluding statement about the direction of blood flow. Refer to the valves in the veins of your hand.

Blood Pressure

During your last visit to a doctor, you may have noticed an apparatus for measuring **blood pressure** hanging on the wall. The gauge may resemble a thermometer; but instead of measuring temperature, this gauge is designed to measure pressure in terms of the height that a column of mercury can be raised. The greater the pressure, the higher the column of mercury rises in the tube. This is the origin of **millimetres of mercury**, the traditional unit for measuring blood pressure. The symbol for this unit is **mmHg**.

▶ **blood pressure:** the pressure exerted by blood against the walls of blood vessels such as arteries

▶ **millimetres of mercury:** a unit for measuring pressure in terms of the height of a column of mercury that can be supported by that pressure

▶ **mmHg:** the symbol for millimetres of mercury

The term *blood pressure* usually refers to the pressure exerted by blood on the walls of a major artery. As shown in Figure A1.7, this is an indirect measurement in which the arterial blood pressure is equal to the pressure of the air in an inflatable cuff around the patient's arm, which is then equal to the pressure exerted by a column of mercury.

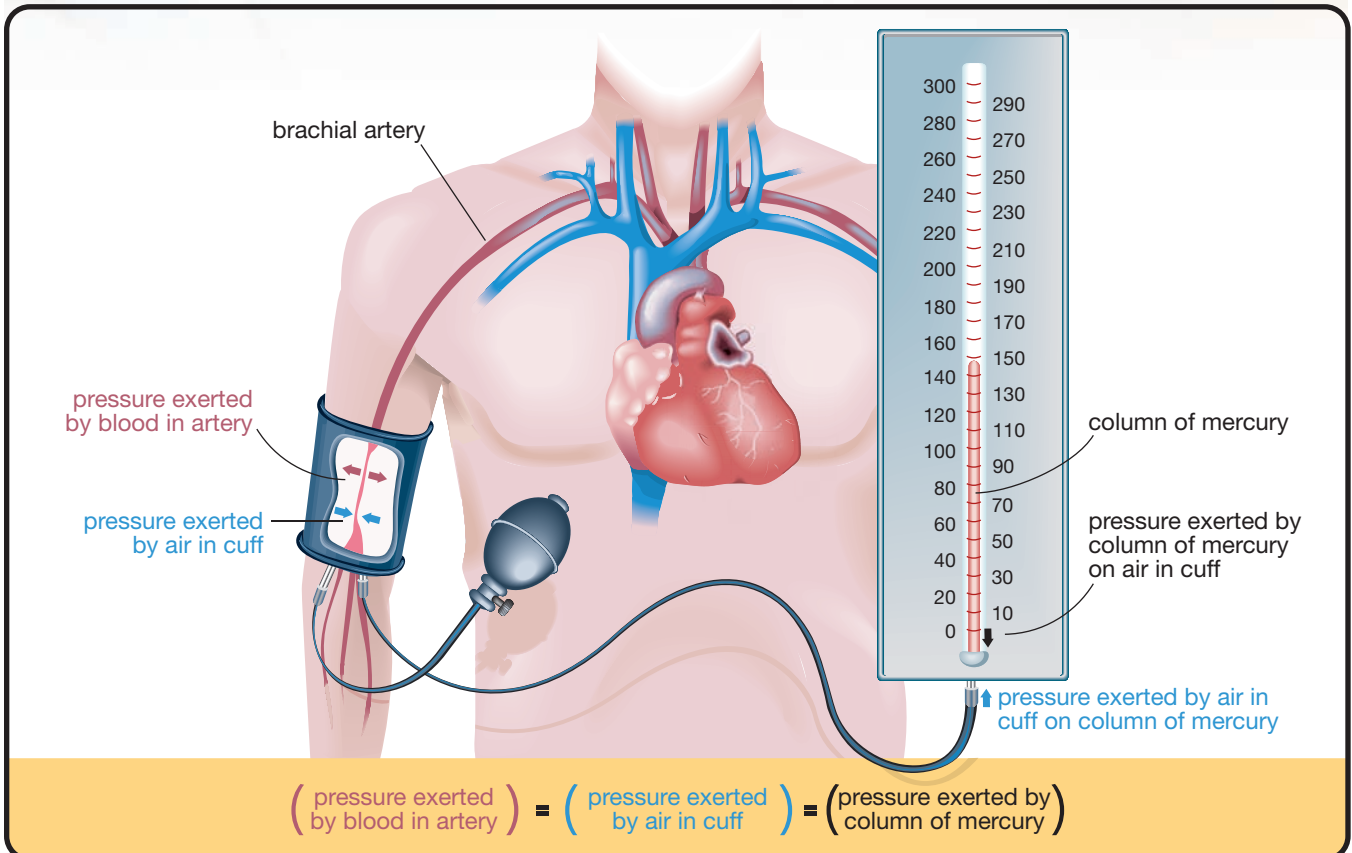


Figure A1.7: The pressure in the column of mercury is equal to the pressure of the blood in the artery.

Blood pressure forces the blood to flow through the body's vessels. Since the heartbeat has a cycle of contraction and relaxation, two pressures are measured with blood pressure.

The first number in a blood pressure reading is the larger **systolic pressure**, which represents pressure in the arteries when the heart's ventricles are contracting. The elastic fibres surrounding the arteries stretch slightly in response to this pressure.

- ▶ **systolic pressure:** the pressure exerted on the artery walls when the heart's ventricles are contracting
- ▶ **diastolic pressure:** the residual pressure exerted on the artery walls when the heart's ventricles are relaxing

The second number, called **diastolic pressure**, is smaller and represents the residual pressure in the arteries when the heart's ventricles are relaxing and the chambers of the blood are refilling. This pressure is due to the elastic walls of the arteries attempting to return to their previous shape between ventricle contractions.

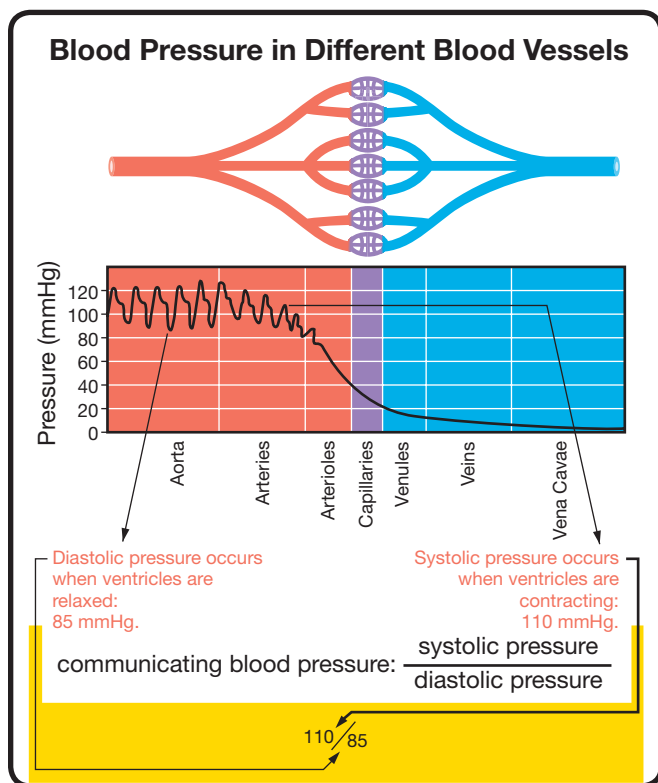


Figure A1.8

Blood pressure is written as systolic pressure over diastolic pressure. Using the values in Figure A1.8, the blood pressure would be 110/85. Even though this blood pressure value is read as 110 over 85, this form of communication is not a fraction, so it should not be simplified or reduced. Note that the units for each individual pressure value are recorded in millimetres of mercury, but no units are recorded when communicating systolic pressure over diastolic pressure: each value is understood to be in millimetres of mercury.

The normal range of blood pressure for adults is a systolic pressure between 90 and 135 mmHg with a diastolic pressure between 50 and 90 mmHg. Blood pressure values in excess of 140/90 are considered to be high blood pressure or **hypertension**.

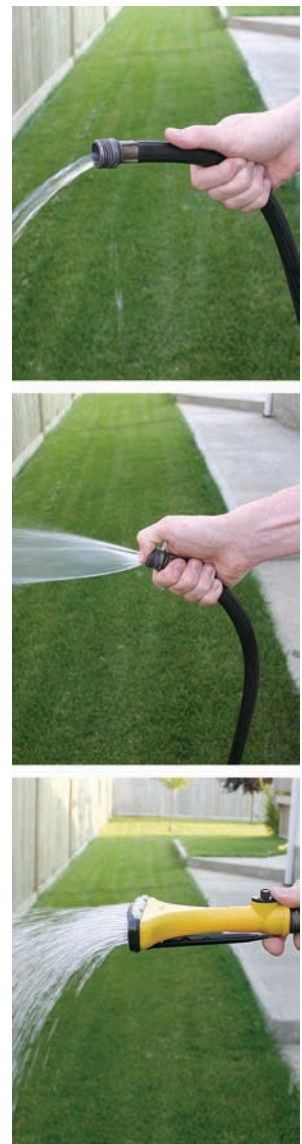
▶ **hypertension:** chronic, abnormally high blood pressure, characterized by values greater than 140/90

Note that by the time blood leaves the arterioles and then enters the capillaries, pressure is significantly reduced. Since the smallest capillaries only allow blood cells to pass in single file, there is more resistance to the blood flow. Therefore, there is a reduction in blood pressure. So, how does blood return to the heart? Recall that the skeletal muscles squeeze the veins during exercise. This is combined with the action of one-way valves within the veins to force blood back to the heart.

Pressure and Blood Flow

As water flows from an outside faucet through a garden hose to a sprinkler or a nozzle, pressure on the water drives it through the hose. If there are no leaks, then the number of litres per minute that leave the hose should equal the number of litres per minute that enter the hose. Although this appears to be stating the obvious, it explains the behaviour of water as it leaves the hose. As an example, consider what happens when you clamp your thumb over the open end of a hose. Why does the flow become a jet-like spray?

If you put your thumb over the end of a hose, you reduce the cross-sectional area of the opening. The small opening forces the water to leave much faster to balance the number of litres per minute that enter the hose at the faucet end. Similarly, if the attachment on the hose's end increases the cross-sectional area, then the speed of the water drops since the larger opening easily accommodates the number of litres per minute entering the hose.



How does this thinking apply to the flow of blood from arteries to capillaries? Even though each individual capillary has a very tiny cross-sectional area, the huge number of capillaries fed by an artery means that the total cross-sectional area is much greater. One result of this is that the speed of the blood drops dramatically as it passes through a capillary bed, as in Figure A1.9. Another result is that the increase in cross-sectional area also contributes to the drop in blood pressure as the blood flows through a capillary bed from the arteries and arterioles.

The fact that blood travels slowly through the capillary bed means that the exchange of substances through diffusion between cells of tissue and the blood is enhanced. As blood leaves the capillary beds, the total cross-sectional area of the vessels decreases. As a result, the blood flow speeds up. However, because blood pressure is so low by the time it leaves the capillary beds, the flow speed through veins is much less than the speed through arteries.

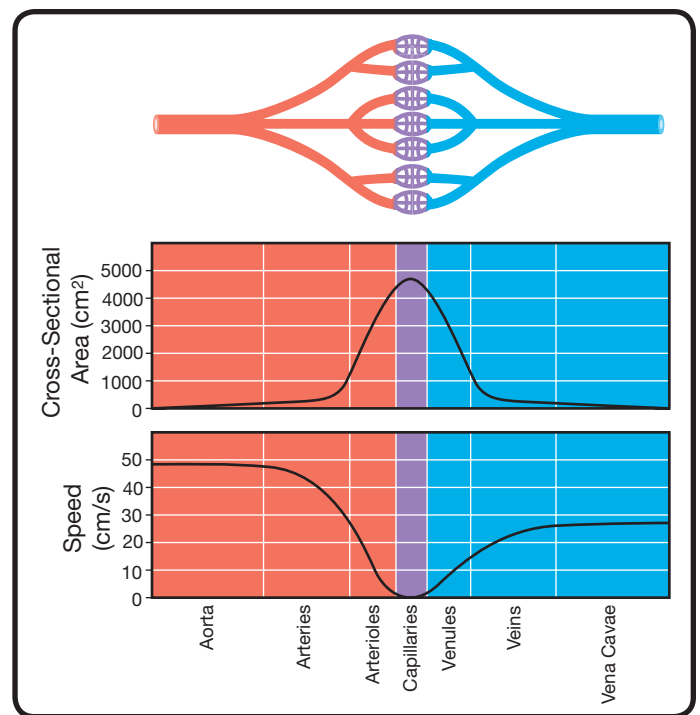


Figure A1.9

Practice

20. While waiting at a pharmacy to pick up a prescription, you decide to have your blood pressure tested using the automated machine available for customers. The machine says that your blood pressure is 138 over 96.
 - a. Explain what the values of 138 and 96 measure. What is happening in your heart and arteries?
 - b. Identify what unit could be included with each measurement you explained in question 20.a.
 - c. Is 138 over 96 a cause for concern? What would you do with this information?
21. During diastole, the heart's ventricles are relaxing but there still is residual pressure in the arteries. Identify the source of this pressure.
22. Explain what causes the blood flow velocity to drop as it passes through the capillaries.



Measuring Blood Pressure

Blood pressure readings are often taken as part of a regular medical checkup. If blood pressure is too high, there is a risk of blood vessels bursting. This would be particularly dangerous if a vessel burst in your heart or brain. If blood pressure is too low, not enough blood can get to all the vital parts of your body. This may cause dizziness or fainting.

Your body has mechanisms to help control the amount of blood pressure. If your blood pressure is low, the blood vessels will be constricted or narrowed. If your blood pressure is high, the blood vessels will be dilated or widened. Many factors affect blood pressure. Readings can vary greatly between individuals due to the strength or rate of heart contractions or the elasticity of arteries. Higher blood pressure readings can also be attributed to anxiety level, exercise, a greater than normal amount of blood in the vessels, viscosity (thickness) of the blood, kidney disease, the presence of chemicals—including caffeine—in the body, or the narrowing of blood vessels due to a buildup of plaque along artery walls.

Investigation

Measuring Blood Pressure

Purpose

You will measure your blood pressure while resting and immediately after exercise.

Background Information

To assess your health, a doctor or nurse may measure your blood pressure using either an automated digital machine or an older type of instrument called a **sphygmomanometer**. To use a sphygmomanometer, the person measuring your blood pressure inflates a cuff around your arm and listens to the sounds of your arteries with a stethoscope. The instant certain sounds change, the height of the column of mercury is noted for that moment.

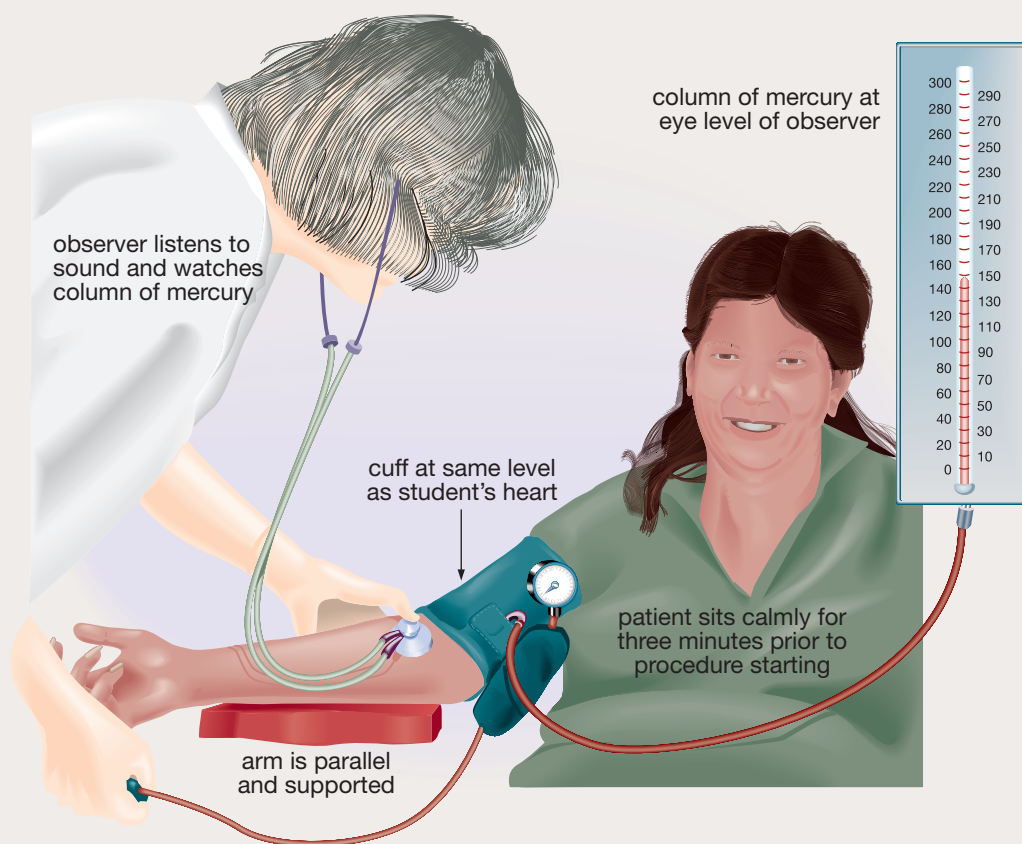
The steps for measuring blood pressure are outlined in the following illustrations.



Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

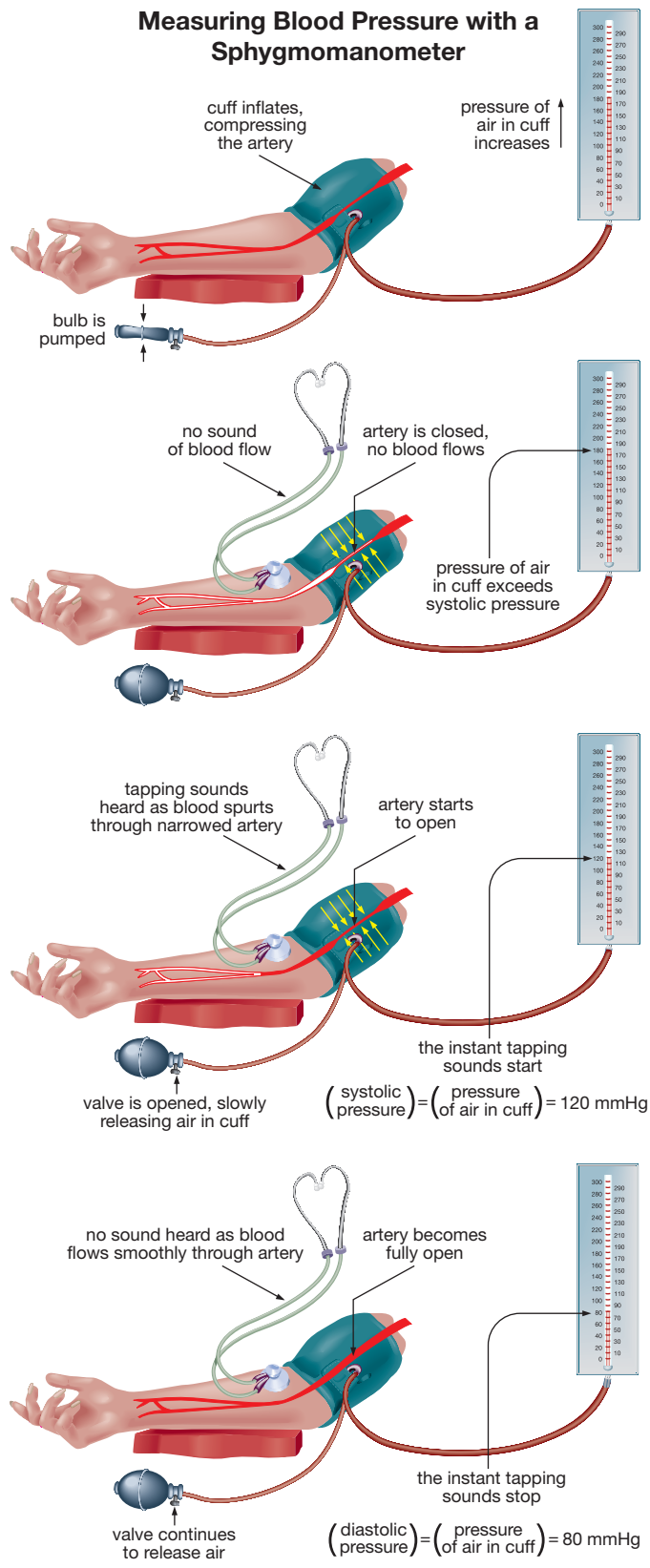
▶ **sphygmomanometer:**
an instrument for
measuring blood pressure



CAUTION!

- Prior to starting this investigation, be sure to carefully read the provided investigation instructions and those details included with the machine that you will be using.
- **Do not exceed 160 mmHg when inflating the cuff on the sphygmomanometer.**
- Remember that only a health-care professional, such as your doctor, can diagnose an abnormality in your blood pressure. A higher than average reading in this investigation is not necessarily an indication of high blood pressure.
- Mercury is a hazardous substance that can produce serious negative health effects. If a sphygmomanometer breaks and mercury spills into the open, the substance must be cleaned up immediately and thoroughly using proper procedures.
- If you have a medical condition that prevents you from participating in physical education classes, you should not participate in the exercising part of this investigation.

Measuring Blood Pressure with a Sphygmomanometer



Procedure

step 1: You should be rested and sitting comfortably before beginning this activity. Using either a digital blood pressure machine or a sphygmomanometer and a stethoscope, have a classmate take your resting blood pressure. Record this number (in mmHg) as your resting blood pressure. If you use a digital machine for measuring blood pressure, follow the instructions provided with that machine. If you do not have access to a sphygmomanometer or a digital machine, measure your blood pressure by visiting a local pharmacy that has an automated blood pressure machine available for customer use.

step 2: Engage in four minutes of physical activity (jumping jacks, running on a spot, stepping up and down from a chair or stool) and have your blood pressure taken again at the end of the four minutes. Be sure that each class member performs the same exercise for the same amount of time for this activity.

Analysis

1. Obtain a class average for resting blood pressure. Compare the class average to the average adult blood pressure of 120 mmHg/ 80 mmHg. Describe how your own resting blood pressure compares to the average adult blood pressure.
2. Compare your blood pressure before and after exercising. Explain why your blood pressure changed after the exercise.
3. Compare the change in your systolic blood pressure reading after exercise to the change in your diastolic blood pressure reading after exercise. Did the readings change by the same amount? Can you account for the changes observed?
4. List some sources of error that may have affected the accuracy of the measurements made in this activity. Describe some improvements that could create more accurate measurements.



In your health file, record your resting blood pressure level and your blood pressure level after exercise.

Investigation

Blood Pressure and Heart Rate

Purpose

You will design an experiment to investigate a factor known to have an effect on blood pressure and heart rate.



Science Skills

✓ Initiating and Planning

Background Information

This investigation will allow you to apply what you have learned so far about blood pressure, heart rate, and the circulatory system. You have already been introduced to several factors known to have an effect on both blood pressures and heart rates.

Choose one of these factors. Then design an experiment that will allow you to test the effect of this factor on both blood pressure and heart rate.

You may decide to undertake some background research on the factor that will be the focus of your experiment. This will help you generate questions and identify what kind of data you will be collecting. It is also useful to research the importance of establishing a double-blind test when designing your experiment.

Process

The end product will be a detailed procedure for an investigation. You'll describe how to complete the necessary measurements and observations.

Procedure

- step 1:** Identify a specific question that needs to be investigated to determine the effects of the variable you have chosen to study.
- step 2:** Identify the manipulated variable, the responding variable, and the control group for your experiment. Based upon your background research, define a double-blind test and relate it to how the data will be collected in this experiment.
- step 3:** Determine what data needs to be collected to answer the question identified in step 1. Describe a means to collect that data, and list the tools required. Be sure to include any necessary safety precautions.
- step 4:** Design and construct data tables to ensure all the necessary observations are made and recorded.

1.2 Summary

The circulatory system's basic components are the heart, the blood vessels, and the blood. In this lesson you learned that vessels in the circulatory system are defined by their size and the direction in which they carry blood, relative to the heart. The vessels are specialized for their specific functions. Capillaries are uniquely designed for the exchange of nutrients between the body's cells and the circulatory system. Because matter exchange between capillaries occurs by diffusion, every cell in the body must be close to a capillary.

The pumping of the heart's ventricles exerts pressure on blood, and this pressure is then transferred to the artery walls. Blood pressure has two readings. The systolic reading is the artery pressure when the heart's ventricles are contracting. The diastolic reading is residual artery pressure when the heart's ventricles are relaxed. When listed separately, the units of millimetres of mercury are included with each of these pressure values. When communicated together, the units are usually omitted and the pressures are communicated as systolic pressure over diastolic pressure. An average blood pressure reading for adults is 120/80. Readings of 140/90 or greater are considered to be high blood pressure or hypertension.

Blood pressure is greatly reduced as the blood flow encounters resistance when passing single file through the many kilometres of tiny capillaries. By the time blood passes to the veins, blood pressure is so low that the blood is helped back to the heart by one-way valves and the contractions of skeletal muscles.

1.2 Questions

Knowledge

- Copy and complete the following table to compare arteries, veins, and capillaries.

| Characteristic | Arteries | Veins | Capillaries |
|---|----------|-------|-------------|
| description of vessel walls | | | |
| direction of vessel blood flow in relation to heart | | | |
| blood oxygen level in vessel | | | |
| colour in a circulatory system diagram | | | |
| blood pressure in vessel | | | |
| valves present | | | |
| pulse present | | | |

Applying Concepts

- People who have type 1 diabetes do not produce insulin—the sugar-regulating hormone—and they must have regular hypodermic insulin injections to regulate their blood sugar. Researchers are working on developing a dry powdered form of insulin that can be delivered by the same kind of inhaler used by people with asthma.
 - Describe some possible benefits of the inhaler delivery system.
 - Insulin is usually injected into fat underneath the skin. List the pathway that injected insulin takes from a capillary bed under the skin to a target cell in the liver.
 - List the pathway that inhaled insulin would take from the lungs to a target cell in the liver.
 - Which of the two delivery methods—injected or inhaled—would be faster at getting to target cells?
- Identify some factors that can cause a person's blood pressure to increase.
- Explain why it is more dangerous if an artery—rather than a vein—is cut in an accident.
- Sketch a capillary bed. Include the artery, the arteriole, the vein, the venule, and the proper placement of valves. Include a few tissue cells being fed by the capillaries. Add arrows to your sketch that indicate the direction of blood flow, and add arrows that show what materials are being exchanged and the exchange direction.
- Soldiers on guard are often required to stand in one place for long periods of time. While standing at attention some of the soldiers sway back and forth, slightly contracting and relaxing their calf muscles. Other soldiers exercise the muscles in their lower legs by slightly wiggling their toes in oversized boots. Soldiers who do not use strategies like these often faint after standing for a long time. Explain why contracting and relaxing the muscles in their lower legs helps prevent soldiers from fainting.

